TECHNICAL REPORT
NATICK/TR-84/005

THE EFFECT OF TEMPERATURE ON ~~THE~~ STRENGTH PROPERTIES OF TENTAGE FABRICS

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NOVEMBER 1983

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NATICK/TR-84/005	2. GOVT ACCESSION NO.: AD-A138920
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): THE EFFECT OF TEMPERATURE ON THE STRENGTH PROPERTIES OF TENTAGE FABRICS	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Alexander Galezewski	8. CONTRACT OR GRANT NUMBER(s): N/A
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Natick Research & Development Center, Aero-Mechanical Engineering Laboratory, Natick, MA 01760	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1L162723AH98, AE052
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Natick Research & Development Center, Aero-Mechanical Engineering Laboratory, Natick, MA 01760	12. REPORT DATE: November 1983
	13. NUMBER OF PAGES: 19
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

ELECTE
MAR 13 1984
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

FABRICS
LAMINATES
MECHANICAL PROPERTIES
STRENGTH
TEMPERATURE

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The influence of temperature on the mechanical properties of three standard military tentage fabrics - Cotton Duck, Sateen, and M-51 - and an experimental fabric was determined. The tensile strength and elongation at break, modulus of elasticity, and tearing strength values were plotted for temperatures between -40° and 180°F (-40° and 82°C). All fabrics became stiffer at low temperatures, as indicated by an increase in the modulus of elasticity. In general, a linear decrease in the tensile and tear properties was observed as temperature increased. The only exception was the tear strength of the M-51 fabric, which

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20. Abstract (cont.)

was higher at 180°F (82°C) than at -40°F (-40°C). Based on the ratio of strength to weight, the most efficient tentage fabric was the experimental fabric. The effect of temperature on the tensile strength of tentage fabrics weakened by weathering outdoors was predicted also.

Preface

The work reported here was carried out under project number 1L162723AH98 entitled "Clothing, Equipment and Shelter Technology".

The author would like to express his thanks to Messrs. Richard Erickson and James Tierney of the Experimental Analysis and Design Division, Aero-Mechanical Engineering Laboratory for their assistance in the testing of tentage fabrics.

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THE EFFECT OF TEMPERATURE ON THE STRENGTH PROPERTIES OF TENTAGE FABRICS

Introduction

Fabrics are widely used in the manufacture of flexible, mobile shelters for the protection of personnel and equipment from a variety of weather conditions, such as sun, wind, rain, and snow. These shelters can take the form of tents, tarpaulins, and various covers. Even if only tents for the U.S. Army were considered, the amounts of fabric involved and their monetary value are large. The stability of tent fabrics at temperatures which can be expected during use in the field is, therefore, of great importance to the Armed Forces. A tentage fabric fails when its tensile strength properties no longer enable it to withstand the combined effect of its own weight, the stresses caused by the supports or frames of the tent structure, and the pressure exerted by wind, rain and snow. Rips that develop necessitate striking the tent and removing it from service for repairs.

From a structural-design point of view, no matter how resistant a tent fabric may be to water, mildew, or fire, it is useless as a shelter cover unless it is strong enough to withstand the condition of field use. The tensile strength properties of a fabric are therefore of primary importance. Of the two tensile properties - breaking and tearing - the latter is considered the more important, as tears is the fabric are a main reason for the premature failure of our current military tentage during service.

The tensile properties of uncoated, coated, and laminated fabrics of a given weight, construction, and finish are largely dependent on the properties and quantity of the yarns and fibers which comprise it. These, in turn are ultimately a function of the state of the polymer.[1] Fundamentally then, the ability of tentage materials to withstand loads at a variety of temperatures is closely dependent on the type of polymer and the extent to which it has been degraded by the action of one or more of the following: solar radiation, ozone, fungi, moisture, industrial pollutants, and chemicals present in the fabric's finish. Considerable amount of work has been done on establishing the mechanical properties of individual fibers for a wide range of temperatures.[2] Unfortunately, however, data on fabrics is rather limited.[3]

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[1] R. W. Moncrieff. Man-Made Fibers, John Wiley & Sons, New York, 6th Edition, 1975.

[2] W. E. Morton and J. W. Hearle. Physical Properties of Textile Fibers, The Textile Institute, Manchester and Heineman, London, 2nd Edition, 1975.

[3] R. M. Crow and M. M. Dewar. The Effect of Low Temperatures on Coated and Uncoated Fabrics. Defense Research Establishment, Ottawa, Canada, Report DREO-R-858, 1982.

The purpose of this investigation was to determine the effect of temperature on the strength properties of four tentage fabrics. A temperature range of -40° to 180°F (-40° to 82°C) was selected as being representative of the surface temperatures encountered is various climates, from arctic cold to desert hot, in which tents are used. This work was undertaken in-house in order to obtain information on a subject on which there is little experimental data available.

Materials

Three current standard Army tentage fabrics and one experimental tentage fabric of interest to the military were selected for this study. Their selection was based on the fact that they represented a wide range of weights, components, and constructions.

Two of the Army fabrics contained cotton fibers: the 15.5 oz/yd^2 (526 g/m^2) Duck[4] and the 9.4 oz/yd^2 (318 g/m^2) Sateen.[5] The third, the 11 oz/yd^2 (373 g/m^2), M-51 fabric[6] was made of a polyester fabric coated with a chloroprene rubber and a polyvinyl fluoride film laminated to one of the coated sides. The experimental fabric, which weighed 6.2 oz/yd^2 (210 g/m^2), was comprised of a nylon fabric, polytetrafluoroethylene film, and an aromatic polyamide fabric. Note that the M-51 and the experimental fabrics are not fabrics in the strict sense of the word, but are laminated, composite materials, which happen to contain fabrics in their construction.

The constructions of the studied fabrics are given in Table 1. A detailed description of the Cotton Duck, Sateen, and M-51 fabrics can be found in the referenced Military Specifications. Additional information on the construction of the laminated experimental fabric is presented next.

The experimental fabric consisted of a polytetrafluoroethylene film sandwiched between a layer of plain-weave, rip-stop nylon fabric and a layer of plain-weave aromatic polyamide fabric. The nylon fabric weighed 1.9 oz/yd^2 (64 g/m^2) and contained 96 yarns per inch (38 yarns per cm) in the warp and filling directions. The aromatic polyamide fabric, Kevlar-29 type, weighed 3 oz/yd^2 (102 g/m^2) and contained 51 yarns per inch (20 yarns per cm) in both directions. The middle layer was 0.7 oz/yd^2 (24 g/m^2) expanded, microporous polytetrafluoroethylene (PTFE) film. These three components were bonded to each other with a polyurethane adhesive that offered a resistance to separation (peel) of the fabric layers from the film layer of 0.6 to 0.8 lb /in. (1.0 to 1.4 N/cm) for the temperature range between -40°F and 180° (-40° and 82°C).

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[4]Military Specification, MIL-C-43627A, Cloth, Duck, Cotton, 1973.

[5]Military Specification, MIL-C-12095F, Cloth, Sateen, Cotton, 1973.

[6]Military Specification, MIL-C-43944, Cloth, Laminated and Cloth, Coated. 1976.

Table 1. Construction of Tentage Fabrics

Fabric	Military Specification	Component	Component Weight		Total Weight		Total Thickness	
			oz/yd^2	(g/m^2)	oz/yd^2	(g/m^2)	mil	(mm)
Cotton Duck	C-43267A	Cotton Fabric	9.9	(336)	15.5	(526)	27	(0.68)
		Chemical Saturant	5.6	(190)				
Sateen	C-12095F	Cotton Fabric	8.0	(271)	9.4	(318)	17	(0.43)
		Chemical Saturant	1.4	(47)				
M-51	C-43944	PVF Film	1.5	(51)				
		Chloroprene Rubber	5.5	(186)	11.0	(373)	15	(0.38)
		Polyester Fabric	4.0	(136)				
Experimental	None	Nylon Fabric	1.9	(64)				
		Adhesive	0.3	(10)				
		PTFE Film	0.7	(24)	6.2	(210)	13	(0.33)
		Adhesive	0.3	(10)				
		Aramid Fabric	3.0	(102)				

Test Procedures

The strength properties of the tentage fabrics were determined with the Instron Testing Machine, Model 1125. For work done at temperatures other than room temperatures, the Instron Machine was equipped with the Instron's Temperature Chamber, Model 3111. Heating of the chamber to test temperatures above ambient was done electrically; cooling was accomplished by releasing liquid nitrogen into an expansion compartment within the chamber and circulating the resulting low-temperature gas throughout the test chamber with a blower.

The tensile strength and elongation at break tests were performed in compliance with the ASTM Method D1682-64, "Breaking Load and Elongation of Textile Fabrics",[7] using cut strips, 1 inch by 7 inches (2.5 cm by 17.8 cm), and a constant rate-of-extension of 0.8 inches (2 cm) per minute.

The modulus of elasticity was calculated using the ASTM Method D882, "Tensile Properties of Thin Plastic Sheeting".[8] For the purpose of this determination, the tensile stress load was calculated by dividing the load by the average original width of the test specimen.

Tearing strength properties were determined according to ASTM Method D2261-71 "Tearing Strength of Woven Fabrics".[7] Tearing strength, as measured by this method, is the force required to continue or propagate a tear started previously in the specimen. The specimen size was 2 inches by 3 inches (5.1 cm by 7.6 cm). A constant rate-of-extension of 2 inches (5.1 cm) per minute was used.

All specimens were tested in the dry condition, that is, the fabrics were conditioned at 55% relative humidity and 70°F (21°C) for several days prior to cutting and testing.

For tests where weathered fabrics were required, the following procedure was used. The fabrics were weathered out of doors in Miami, Florida on rigid wooden frames. The specimens were stapled to the 12-inch by 12-inch (30.5 cm by 30.5-cm) frames with their warp direction running from the top to the bottom of the frame. The frames were then placed in racks at a 45° angle and were positioned in such a manner that the fabric surfaces faced South. The specimens were removed from the exposure area at the end of six months. During the exposure period, which ran from October to April, the fabrics were subjected to solar radiation amounting to a total of 65,650 Langleys (1 Langley = 1g-cal/cm^2). The weathered fabrics were tested in the dry condition in accordance with the previously mentioned ASTM methods, at 70°F (21°C) only.

[7] American Society for Testing and Materials, Book of ASTM Standards, Part 32, Philadelphia, 1982.

[8] American Society for Testing and Materials, Book of ASTM Standards, Part 35, Philadelphia, 1982.

Results and Discussion

The breaking strength, elongation at break, and tearing strength values for the warp and filling directions for the four tentage fabrics tested at 70° (21°C) are given in Table 2. Tests carried out at temperatures other than the average room temperature, 70°F (21°C), are very time-consuming due to the need for equilibration of the test specimens. For this reason, only one direction, the warp direction, was chosen for our study of the temperature eff[illegible] on the strength properties of these fabrics.

Table 2. Average Breaking Strength, Elongation at Break and Tearing Strength Values for the Warp and Filling Directions of Tentage Fabrics Tested at 70°F (21°C)

Fabric	Breaking Strength Warp/Filling		Elongation at Break Warp/Filling	Tearing Strength Warp/Filling	
	lb/in	(N/cm)	Percent	lb	(N)
Cotton Duck	104/103	(182/180)	18/13	6/6	(27/27)
Sateen	162/91	(284/159)	5.5/14	5/5	(22/22)
M-51	206/157	(361/275)	22.5/26	24/38	(107/169)
Experimental	365/304	(639/532)	6.5/5	64/65	(285/289)

The influence of temperature on the breaking strength of tentage fabrics is illustrated in Figure 1. The relationship between these two variables shows a linear decrease in breaking strength as temperature increases from -40° to 180°F (-40° to 82°C). The Cotton Duck, a heavy fabric with a weight of 15.5 oz/yd^2 (526 g/m^2), has the lowest breaking strength; the experimental fabric, which weighs only 6.2 oz/yd^2 (210 g/m^2), is the strongest. The rate with which the strength of tentage fabrics decreases (the slope of the line) is approximately equal for all four fabrics tested. However, for two fabrics, the Cotton Duck and the Sateen, this decrease is much more significant than for the M-51 and for the experimental fabric because the former two break in tension at lower loads. If, for example, one selects the tensile values at 70°F (21°C) as the reference points, then it can be seen that at 180°F (82°C) the experimental fabric retains 97% of its strength, M-51 almost 83%, Sateen about 75%, but the Cotton Duck retains only 62% of its initial strength at 70°F (21°C).

The dependence of the elongation at break on temperature is shown in Figure 2. At -40°F (-40°C) the Sateen elongates by 6%, the experimental fabric by 7.5%, the Cotton Duck by 19.5%, and the M-51 by 20.5%. All of these

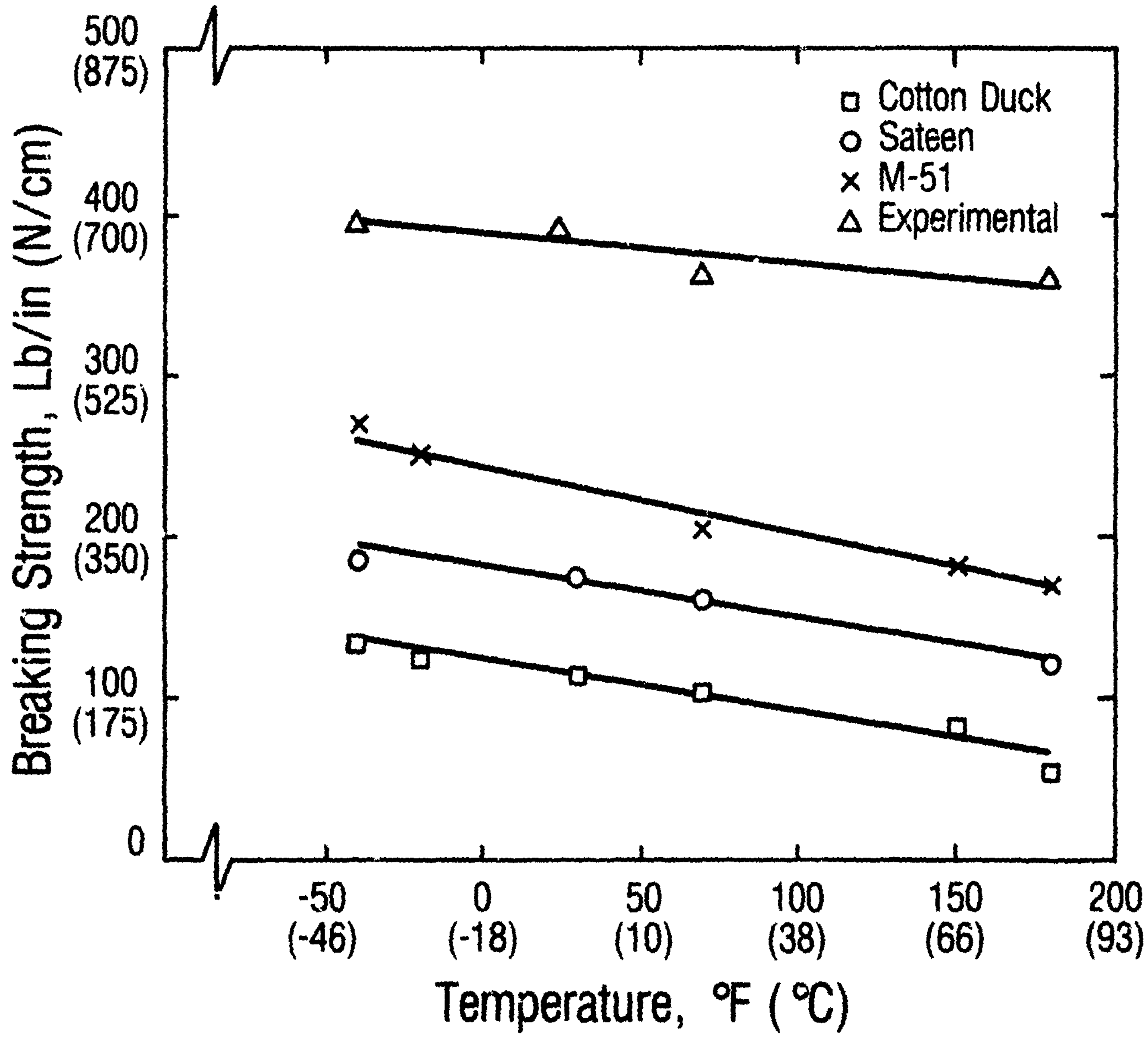

Figure 1. Breaking Strength of Tentage Fabrics in the Warp Direction as a Function of Temperature

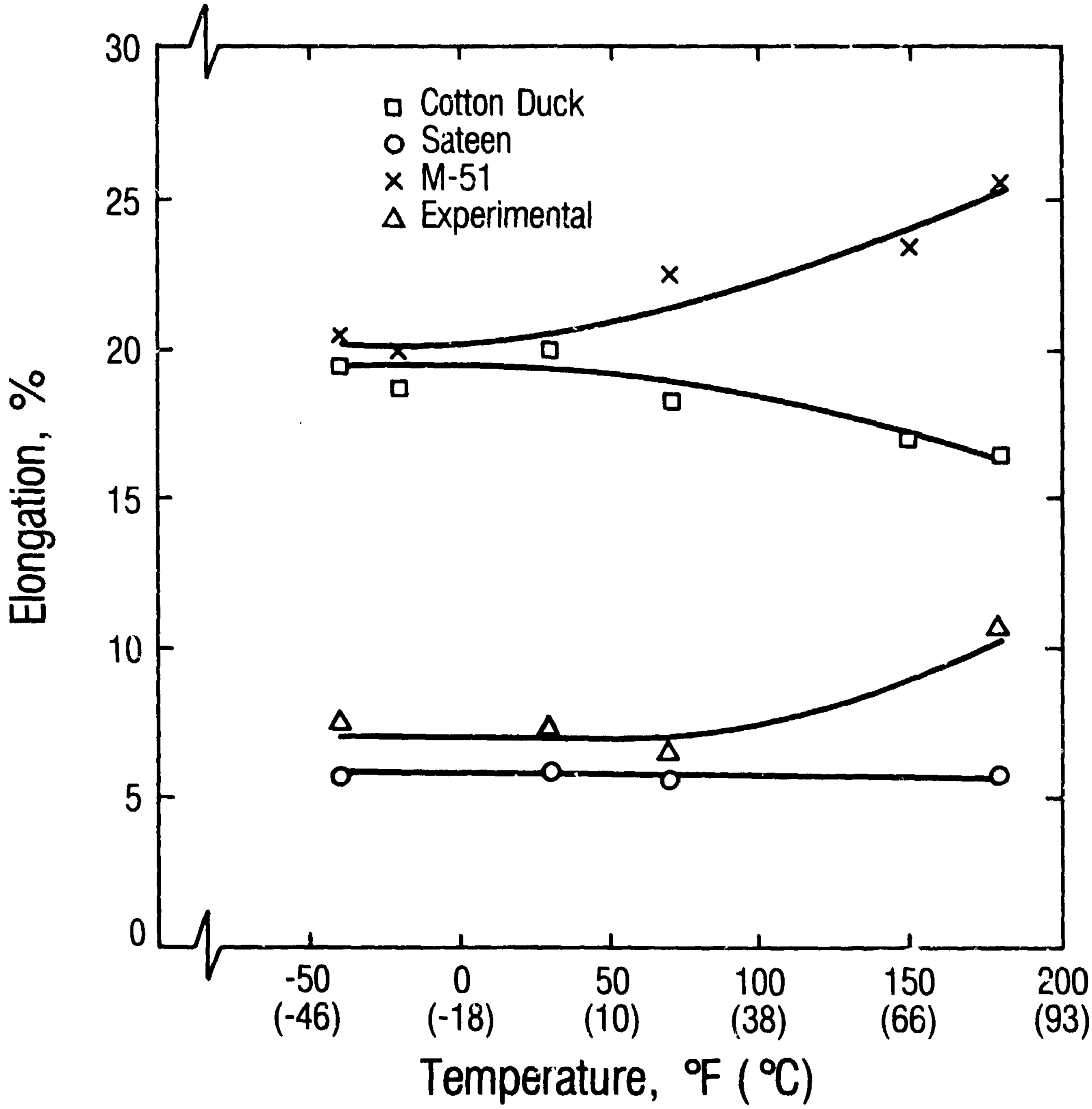

Figure 2. Elongation at Break of Tentage Fabrics in the Warp Direction as a Function of Temperature

fabrics show almost no increase in elongation at temperatures between -40°F (40°C) and 50°F (10°C). Above 50°F (10°C), however, a variety of elongation patterns was noticed. The two strongest fabrics, the experimental and M-51, had the largest change in elongation. At 180°F (82°C), for example, their elongation increased to 11% and 25.5%, respectively, but there was no change in elongation for the Sateen, and the elongation of the Cotton Duck fabric decreased to 16.5%.

A decrease in the modulus of elasticity with an increase in temperature was observed for all fabrics. The experimental fabric had the highest moduli and Cotton Duck the lowest, as evidenced in Table 3. Typical stress-strain curves obtained at three temperatures can be seen in Figure 3.

Table 3. Temperature Dependence of Modulus of Elasticity for Tentage Fabrics

	Warp		Warp		Warp		Filling	
Fabric	-40°F	(-40°C)	70°F	(21°C)	180°F	(82°C)	70°F	(21°C)
	lb/in	(N/cm)	lb/in	(N/cm)	lb/in	(N/cm)	lb/in	(N/cm)
Cotton Duck	664	(1163)	571	(1000)	518	(907)	792	(1387)
Sateen	4569	(8000)	4016	(7032)	3490	(6111)	850	(1488)
M-51	3163	(5538)	2641	(4624)	739	(1294)	804	(1408)
Experimental	9866	(17275)	9478	(16596)	7818	(13689)	6080	(10646)

The influence of temperature on the tearing strength of tentage fabrics is presented in Figure 4. The slopes of the lines for the Cotton Duck and Sateen fabrics do not seem at first glance to indicate a significant decrease in strength with a rise in temperature. Nevertheless, because of their low values of resistance to tear, the drop in their tearing strength from -40° to 180°F (-40° to 82°C) amounts to approximately 45%. The best resistance to tear is shown by the experimental fabric. It, too, is stronger at -40°F (-40°C) than at 180°F (82°C).

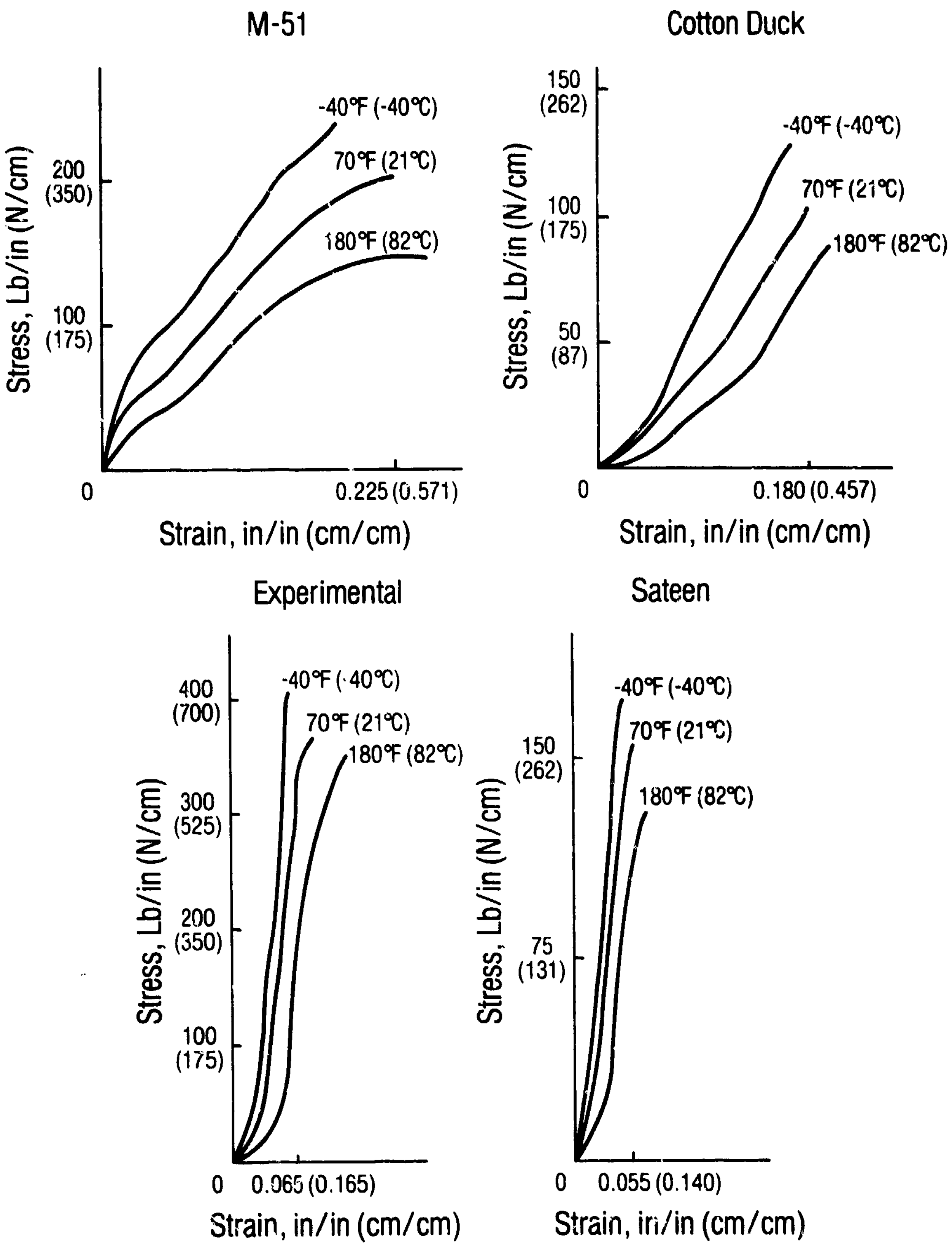

Figure 3. Typical Stress-Strain Curves for the Warp Direction of Experimental, Sateen, M-51, and Cotton Duck Fabrics Obtained at Three Temperatures

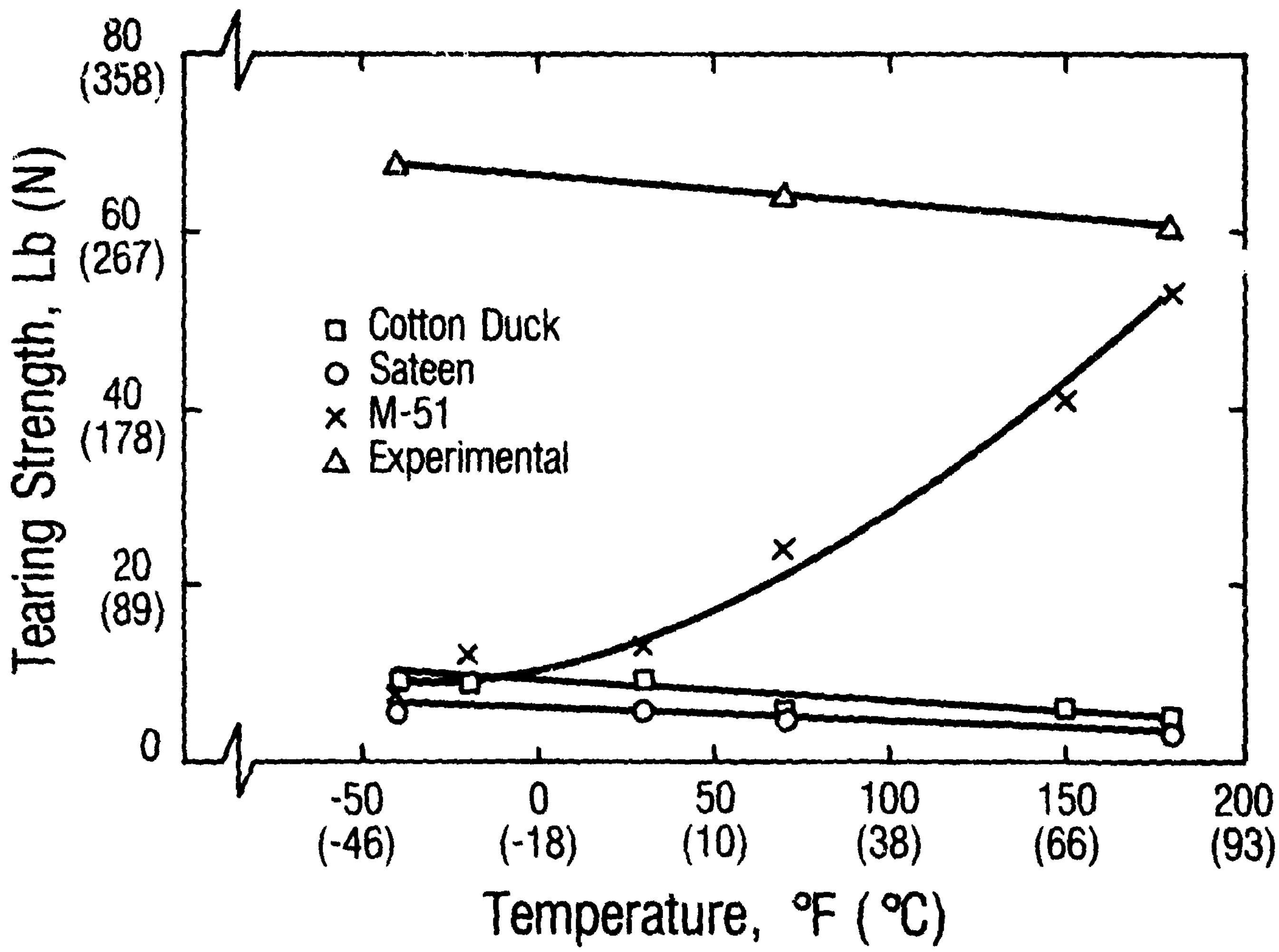

Figure 4. Tearing Strength of Tentage Fabrics in the Warp Direction as a Function of Temperature

A completely different behavior is displayed by the M-51 fabric. The curve for the M-51 fabric indicates a steady increase in resistance to tear from -40° to 180°F (-40° to 82°C), which is due to the thermoplastic nature of the polyester fibers and the elastomeric chloroprene coating. The polyester fibers move and orient themselves more easily in the direction of applied loads, prior to breaking, than the cotton and polyamide fibers of the other three fabrics. This ease of fiber realignment leads to higher tear strength values for the M-51 fabric at 180°F (82°C) than at -40°F (-40°C).

The relationship between strength at 70°F (21°C) and weight of tentage fabrics is shown in Table 4. By expressing the response of each evaluated fabric to applied loads in tension (either breaking or tearing) as the ratio of its strength to its weight, it becomes very clear that the most efficient tentage fabric was the experimental fabric and the least efficient was the Cotton Duck fabric. This trend remained constant throughout the -40° to 180°F (-40° to 82°C) temperature range.

Table 4. The Relationship Between Strength in the Warp Direction and Weight for Tentage Fabrics at 70°F (21°C)

Fabric	Weight		Breaking Strength		Tearing Strength		Ratio of Breaking Strength to Weight	Ratio of Tearing Strength to Weight
	oz/yd^2	(g/m^2)	lb/in	(N/cm)	lb	(N)		
Cotton Duck	15.5	(526)	104	(182)	6	(27)	6.7	.04
Sateen	9.4	(318)	162	(284)	5	(22)	17.1	0.5
M-51	11.0	(373)	206	(361)	24	(107)	18.7	2.2
Experimental	6.2	(210)	365	(639)	64	(285)	58.9	10.3

To obtain a general idea of the degree to which temperature will affect the strength of tentage fabrics exposed to weathering, matching samples of three fabrics were placed out of doors in Miami, Florida for six months. Data on breaking strength, elongation at break, and tearing strength for the Sateen, Cotton Duck and experimental fabrics before and after weathering are presented in Table 5. The experimental fabric was weathered with its Nylon fabric side facing the elements. The M-51 fabric was not included in this study because a long-term resistance to weathering of its outermost component, the olive-green pigmented polyvinyl fluoride (PVF) film, is well established, and the data indicate that no decrease in strength could be expected after weathering it for a period of one year (the anticipated life span for tents). The results given in Table 5 indicate that after only a 6-month outdoors exposure, the fabrics can lose a considerable portion of their initial strength. If we look at the breaking strengths, for example, it can be seen that both the Cotton Duck and the experimental fabrics lost 21% of their initial strength, and the Sateen 49%. As far as the tear strength of the fabrics is concerned, the decrease was 16, 25, and 60%, respectively. Further decrease of the strength properties can be expected for samples subjected to weathering for periods longer than six months. The loss in breaking and tearing strength will, however, be less significant for the experimental fabric because of its high initial strength.

Table 5. Average Breaking Strength, Elongation at Break and Tearing Strength Values for the Warp Direction of Tentage Fabrics, Before and After Weathering for Six Months, Tested at 70°F (21°C)

Fabric	Breaking Strength Before/After Weathering		Elongation at Break Before/After Weathering	Tearing Strength Before/After Weathering	
	lb/in	(N/cm)	Percent	lb	(N)
Cotton Duck	104/82	(182/144)	18/17	6/5	(27/22)
Sateen	162/83	(284/145)	5.5/5	5/2	(22/8.9)
Experimental	365/286	(639/501)	6.5/8	64/48	(285/213)

The effect of temperature on the breaking strength values of three fabrics before and after weathering outdoors for six months is shown graphically in Figure 5. A part of this graph is a re-plot of data for the unexposed Cotton Duck, Sateen, and experimental fabrics presented in Figure 1; the values for the weathered fabrics are extrapolated beyond 70°F (21°C) by drawing lines parallel to those of the unexposed fabrics. As may be seen from Figure 5, the temperature has a pronounced influence on the magnitude of the breaking strength of fabrics unexposed to weathering; this influence may become critical, to the point of premature failures, for fabrics already weakened by the out of doors exposure.

Thus, the results of this work indicate the signficant effect of the environment - the combined influence of temperature and weathering - on the performance of tentage fabrics. Moreover, the results demonstrate the importance of this type of data for the design of tents, especially for those incorporating lightweight fabrics, 9 oz/yd^2 (305 g/m^2) or lower, if premature failures are to be avoided.

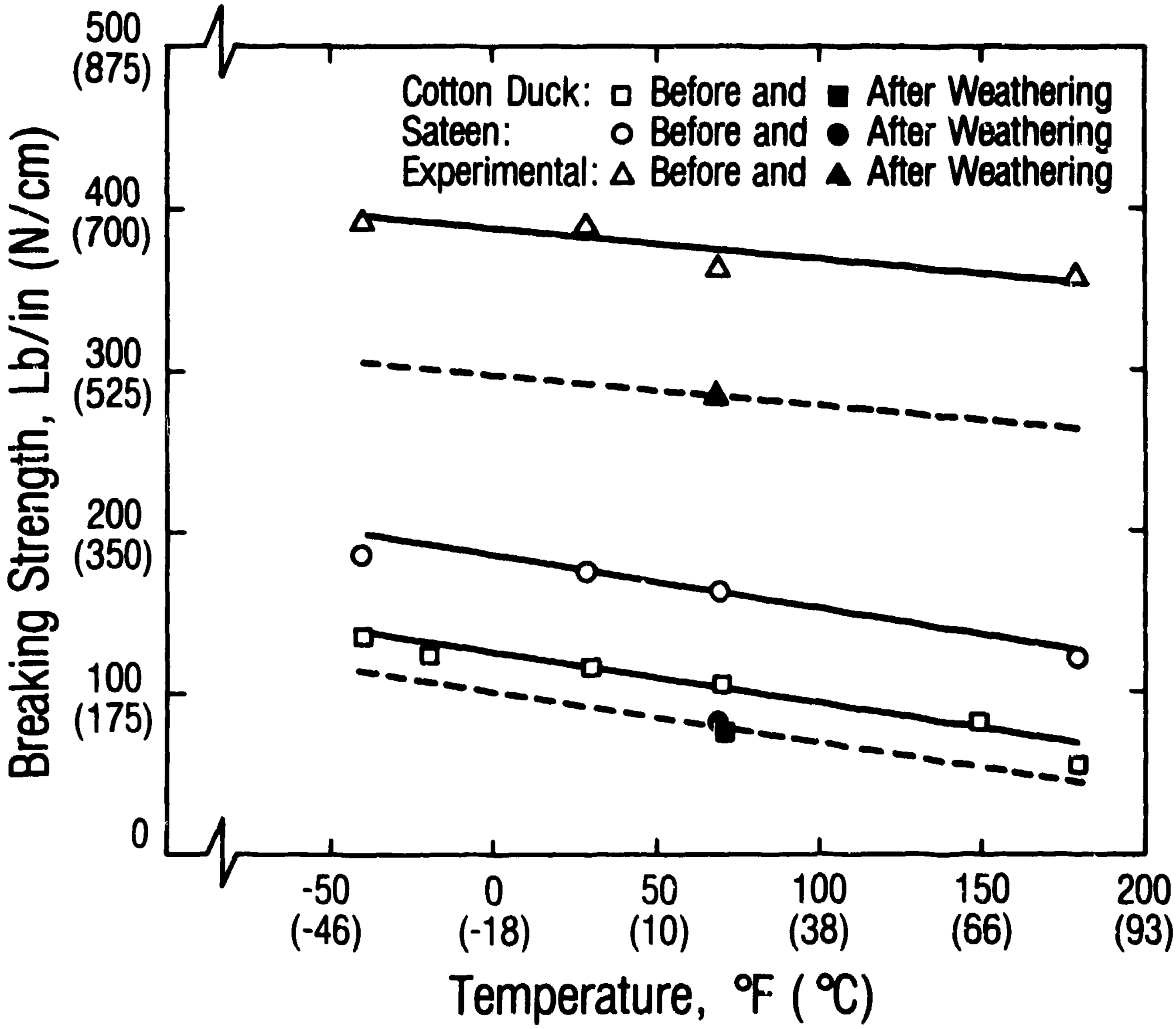

Figure 5. The Effect of Temperature on Breaking Strength of Tentage Fabrics in the Warp Direction Before and After Weathering for Six Months

Conclusions

Because tents are used in a variety of climates, from cold (arctic) to hot (desert), they will be subjected to a wide range of temperatures. It is therefore important to know how they will function under the most extreme of temperatures. Our data demonstrate that the mechanical properties, such as breaking strength, elongation at break, modulus of elasticity, and tear strength, of four tentage fabrics - Sateen, Cotton Duck, M-51, and experimental - were temperature dependent between -40° and 180°F (-40° and 82°C). All fabrics became stiffer at low temperatures, as indicated by an increase in the modulus of elasticity. In general, a linear decrease in the breaking and tearing strength was observed as temperature increased: the tested fabrics were stronger at -40°F (-40°C) than at 180°F (82°C). The only exception was the tear strength of the M-51 fabric, which was higher at 180°F (82°C) than at -40°F (-40°C).

Based on the ratio of strength to weight, the most efficient tentage fabric, at any temperature within the -40° to 180°F (-40° to 82°C) interval, was the experimental fabric, which is comprised of aromatic polyamide fibers. The M-51, which is based on polyester fibers, was the next most efficient, and the cotton-containing Duck and Sateen fabrics were, by far, the weakest.

A short-term exposure of tentage fabrics to out-of-doors weathering in Miami, Florida caused a noticeable degradation of their strength properties. Because elevated temperatures were found to produce a significant weakening of the unexposed fabrics, the effect of these temperatures on the strength of the exposed, weather-weakened fabrics was a further lowering of their strength.

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